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Analysis of Running Skyline With DRAG

Ward W. Carson

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

Analysis of Running Skyline With Drag

Reference Abstract

Carson, Ward W.
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Discusses the mathematical description of a running skyline system which is used to drag logs in a timber harvesting operation. The description is the foundation for a method of computer prediction of the load-carrying capability of these systems. This information is useful to logging engineers in developing harvesting plans for running skyline logging operations.

Keywords: Skidding, cable skidding methods, computers (electronic).

RESEARCH SUMMARY
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For several years, logging engineers involved in developing harvesting plans for the running skyline have been using computational methods to determine the load-carrying capability of these systems. The methods available for these computations have been either hand procedures or digital computer solutions for the specific configurations of a log load suspended free of the ground or in frictionless contact with level ground. The more typical operation, however, drags one end of the log load along the ground. The dragging configuration, considered in this paper, can influence the load-carrying capability of a running skyline significantly.

The dragging log problem was posed mathematically as a requirement to determine the deflection of a loaded skyline when the anchoring geometry, the log-to-ground geometry, the coefficient of friction between ground and log, the weight of cables, and the operating tension of the system are considered known. The description and method used to analyze the dragging log configuration did not account for the exact weight associated with catenary shaped cables but rather approximated their weights with a straight-line assumption. This allowed an algorithm that converges rapidly and provides a high degree of accuracy.

The solution procedure reported in this paper was used in a computer program reported in another publication, "Programs for Skyline Planning," USDA Forest Service General Technical Report PNW-31. Those programs are being used by many logging engineers in the USDA Forest Service, other Government agencies, universities, and the private sector of the timber industry.

CONTENTS

1.0 Introduction

For several years, timber harvest planners have been designing skyline logging operations for the running skyline. One major step in this planning process is the determination of the load-carrying capability of the skyline while anchored in specific geometry and operating over specific terrain. Several methods have been available to compute these capabilities (Carson and Studier 1973, Carson et al. 1971, Lysons and Mann 1967, Mann 1969, Suddarth 1970); however, each method is based on the assumption that the load consists exclusively of the vertical component as would result from either a log load suspended free of the ground or in frictionless contact with level ground. Such is not generally the case in actual operation. Although the loads may be held free of the ground over streams or other sensitive terrain features, it is more typical to drag one end of the log load on the ground. In this configuration, a portion of the load is borne by the ground which increases the size of load that can be carried but adds another force due to the drag of the load on the ground. Planners of a running skyline harvest layout for this type of operation need to determine the influence of drag upon the capability of the system.

This paper presents a mathematical method for determination of loading conditions when the logs are being dragged along the ground by a running skyline. The method is an extension of that discussed by Carson and Mann (1971). Carson (1975) reported on a programed solution based on this method.

2.0 Mathematical Problem

A large part of the mathematical description of the running skyline problem presented by Carson and Mann (1971) applies to the problem treated in this paper. Their statement of the problem was based on a schematic representation of the skyline as shown in figure 1. This figure identifies the

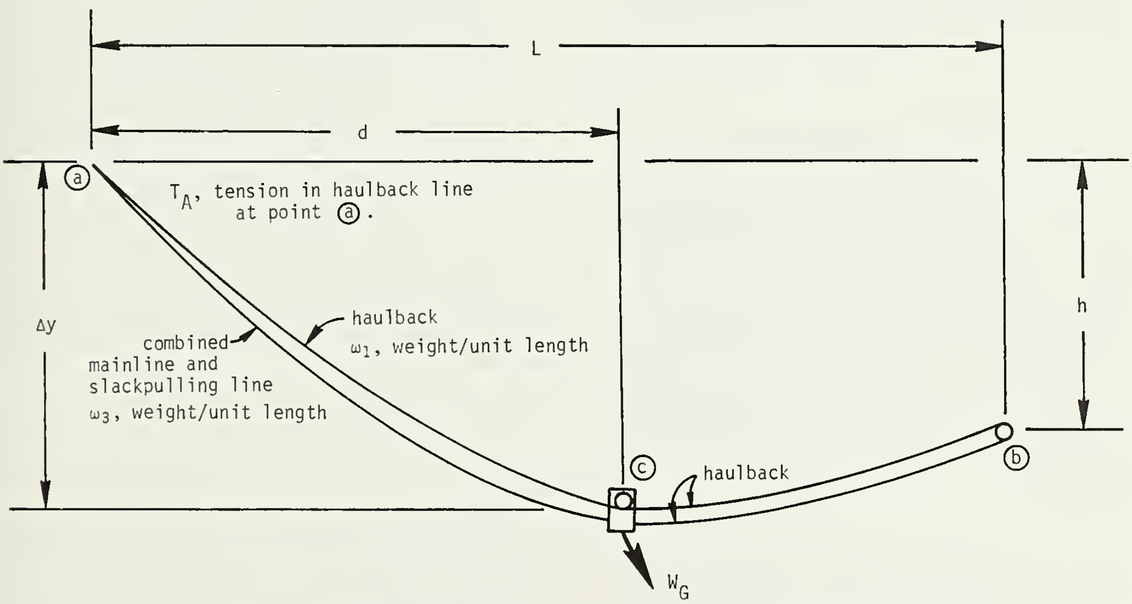

Figure 1.--Schematic of the running skyline.

important geometric variables of span L, vertical anchor point separation, h, and the carriage location coordinates, d and Δy. As in Carson and Mann's paper, the weight per foot of the haulback line, ω_1, and the weight per foot of the combined main line and slack-pulling (or grapple opening) line, ω_3, are assumed to be known. Again, the haulback operating tension, T_A, is taken as a known quantity.

The extension presented in this paper results from the allowance for a more general loading situation. The vertically oriented gross payload in the Carson and Mann (1971) paper is replaced with a vertical carriage load, W_C, plus a log load with drag which combines to give a resultant gross load, W_G, that is not vertical in general.

The analysis presented here then addresses itself to determination of the displacement, Δy, necessary to support the load represented by W_G while the skyline system is maintaining a haulback tension, T_A. A curve connecting a series of these displacements at several locations in the span (i.e., several d's) is referred to as the load path.

2.1 PROBLEM FORMULATION

Carson and Mann (1971) presented an analytical approach to the running skyline problem that averted the difficulties associated with the catenary description of cable problems. This approach, called the force balance formulation, will be used here also for the benefit of a simplified mathematical description. The efficiency of the method and the accuracy were documented by Carson and Mann.

2.2 FORCE BALANCE FORMULATION

The relationship between cable forces and geometry can be derived by consideration of the equilibrium of components of the running skyline system. The equations are written from force and moment balances for all line segments and for the skyline carriage (see fig. 2). For example, line segment 1 can be described by the vertical force balance on the line segment,

$$V_1^a = R_1 + V_1^c;$$

the horizontal force balance on the line segment,

$$H_1 = \text{constant};$$

and the moment balance about the carriage,

$$V_1^a = R_1 \frac{e_1}{d} + H_1 \frac{\Delta y}{d} .$$

In these expressions, R_1 represents the weight of the cable segment concentrated at a horizontal distance, e_1, from the carriage; and the other forces and distances are described in figure 2.

The other line segments can be described by similar expressions so that the vertical forces at the carriage can be stated as

$$V_1^c = R_1 \left(\frac{e_1}{d} - 1\right) + H_1 \frac{\Delta y}{d} \qquad (2.2.1)$$

$$V_2^c = R_2 \left(\frac{e_2}{L-d} - 1\right) + H_2 \frac{\Delta y-h}{L-d} \qquad (2.2.2)$$

and $$V_3^c = R_3 \left(\frac{e_3}{d} - 1\right) + H_3 \frac{\Delta y}{d} \qquad (2.2.3)$$

These forces can be related to the forces on the carriage through the force balance equations

$$V_1^c + 2V_2^c + V_3^c = W_V + W_C \qquad (2.2.4)$$

and $$H_1 + H_3 - 2H_2 = W_H \qquad (2.2.5)$$

These equations include representation for a load vector that may include both vertical, W_V, and horizontal, W_H, components as well as the vertical component of the carriage weight, W_C.

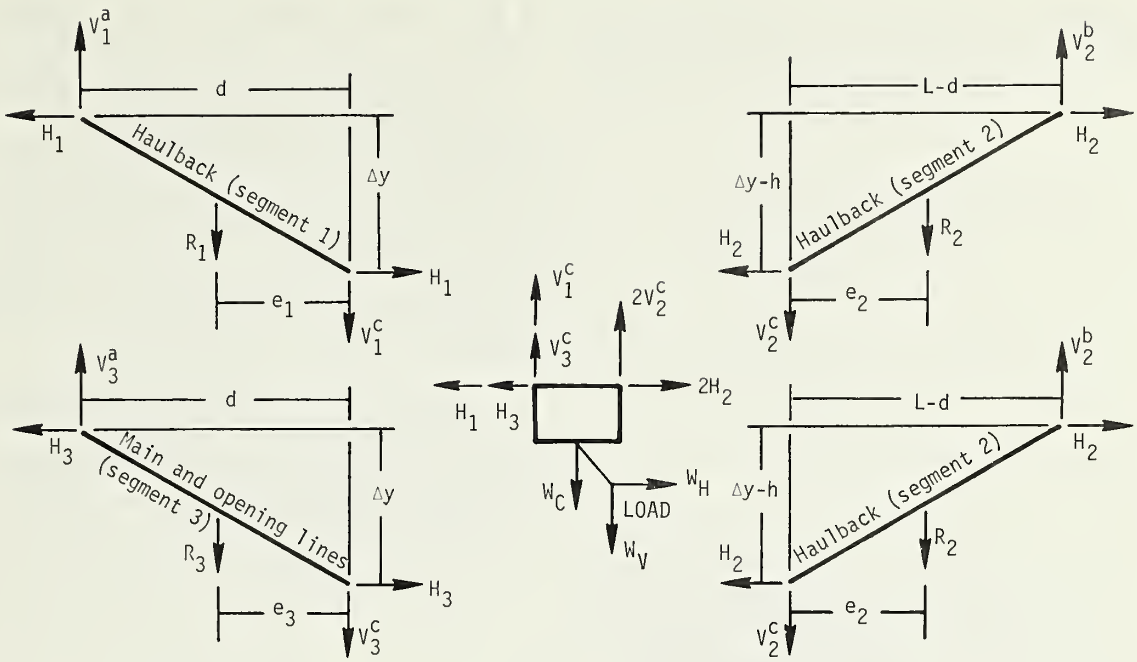

Figure 2.--Force balance formulation.

In a later section, the load vectors, W_V and W_H, will be expressed in terms of conditions experienced by a dragging log load. To implement a solution procedure for determination of the influence of these vectors upon the geometry and tension of the cable configuration, the equations of this section are combined to yield

$$W_V + W_C - W_H \frac{\Delta y}{d} = 2H_2 \left(\frac{\Delta y - h}{L-d} + \frac{\Delta y}{d}\right) + R_1 \left(\frac{e_1}{d} - 1\right) + 2R_2 \left(\frac{e_2}{L-d} - 1\right) + R_3 \left(\frac{e_3}{d} - 1\right) \quad (2.2.6)$$

This equation forms a clear statement of the relationship between the loading at the carriage and the geometry, cable weights, and haulback cable tensions. It will be used in "Solution Procedure" (section 4.0).

2.3 FORCE BALANCE FORMULATION WITH STRAIGHT-LINE APPROXIMATIONS

The equations of the last section require the weights, R_i, and moment arms, e_i, of each segment. The catenary lengths and shapes of these segments, however, are not known until solutions for tensions in each line have been established. Therefore, an exact solution would require iterations involving assumed tensions which provide catenary geometry, line weights, and moment arms, followed by computation of tensions to be compared with the values originally assumed (Carson and Mann 1971). This procedure can be simplified by approximating the catenary geometry of cable segments by straight-line segments between anchor points. The line segments are envisioned as straight, rigid members with the uniform weight distribution of the cables and pinned at a, b, and c (fig. 1). This

assumption allows the line segments weights and moment arms to be expressed as

$$R_1 = \omega_1 \, (d^2 + \Delta y^2)^{1/2}$$

$$e_1 = d/2$$

$$R_2 = \omega_1 \left((L-d)^2 + (\Delta y-h)^2\right)^{1/2}$$

$$e_2 = (L-d)/2$$

$$R_3 = \omega_3 \, (d^2 + \Delta y^2)^{1/2}$$

and

$$e_3 = d/2.$$

This assumption is made in the present analysis. The error introduced in the results is slight. Magnitudes of the error were discussed by Carson and Mann (1971).

3.0 Forces Due to Log Drag

An important part of this analysis is the identification of the forces associated with the dragging log load. The algorithm discussed in the previous section presumed that the horizontal and vertical components of this load could be provided as a function of the information about the log and how it is dragged over the terrain. Expressions for these forces are derived in this section.

Consider the log skidding geometry and force vectors as displayed in figure 3. This figure identifies the horizontal and vertical forces so that they can be expressed as

$$W_V = T\cos\alpha = W - N\cos\theta + N\mu\sin\theta \qquad (3.0.1)$$

and

$$W_H = T\sin\alpha = N\sin\theta + N\mu\cos\theta \qquad (3.0.2)$$

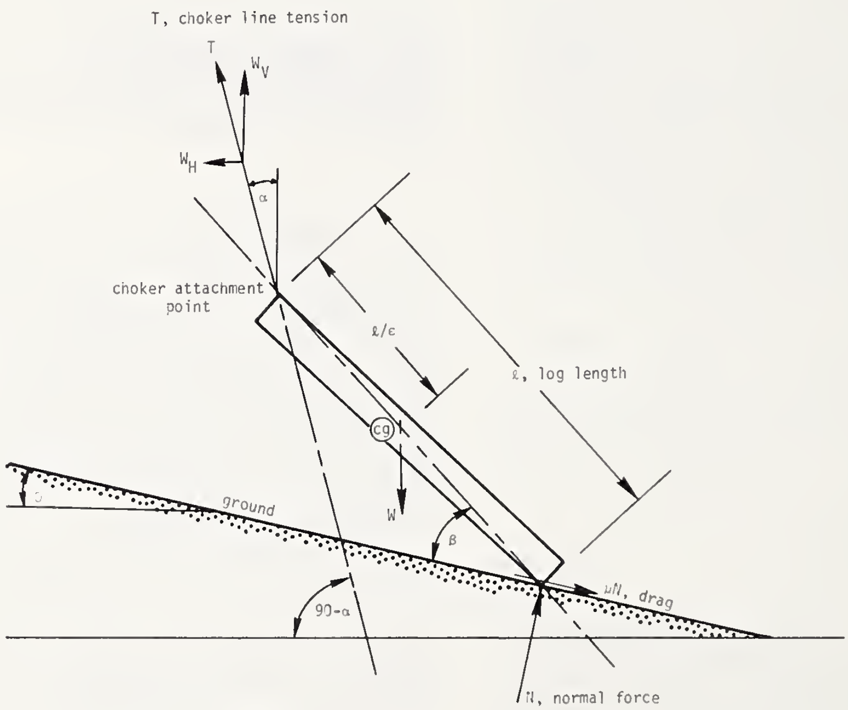

Figure 3.--Log skidding geometry.

where

T = the tension in the choker line,

α = the angle of the choker line with respect to the vertical,

θ = the local slope of the ground,

N = the normal force,

and

μ = the coefficient of friction between the log and the ground.

The normal force, N, is unknown but can be established in terms of the log weight, W, the angle the log makes with the ground, β, and the location of the log center of gravity with respect to the choker attachment point. The expression relating these variables is

$$N = W/\left[\varepsilon\left(\cos\theta-\mu\sin\theta + \sin\theta\tan(\theta+\beta) + \mu\cos\theta\tan(\theta+\beta)\right)\right]$$

This equation shows that the magnitude of the forces involved in the dragging log can be expressed independently of log length and choker length if the angles θ and β are available. By introducing the equation for the normal force, N, into the expressions for W_V and W_H, one obtains

$$W_V = W\left(1 - \frac{\cos\theta-\sin\theta\tan\beta}{\varepsilon(1+\mu\tan\beta)}(\cos\theta-\mu\sin\theta)\right) \quad (3.0.3)$$

$$W_H = W\left(\frac{\cos\theta-\sin\theta\tan\beta}{\varepsilon(1+\mu\tan\beta)}\right)(\sin\theta+\mu\cos\theta) \quad (3.0.4)$$

If the cable between the log load and the carriage is assumed to be weightless, these equations satisfy the requirement for establishing W_V and W_H in terms of the information about the log only.

4.0 Solution Procedure

Recall that the goal of this analysis was to determine the displacement, Δy, required to support a log and carriage load represented by W_V, W_H, and W_C. This will depend, of course, upon the tension, T_A, maintained in the haulback line. This dependence can be expressed by rearranging equation (2.2.6) into the form

$$\Delta y = \frac{W_V+W_C+2H_2h/(L-d)+1/2(R_1+2R_2+R_3)}{W_H/d+2H_2/(L-d)+2H_2/d} \quad (4.0.1)$$

where

H_2 is a function of T_A through the catenary relationship

$$(T_A - \omega_1\,\Delta y) = \left((V_2^c)^2 + (H_2)^2\right)^{1/2} \quad (4.0.2)$$

Unfortunately, the displacement, Δy, remains implicit in all these expressions and cannot be solved for directly. An iterative type solution is required.

The method chosen to solve for Δy is displayed in the flow chart of figure 4. It is not a standard technique; however, for this problem it provides rapid and stable convergence.

5.0 Numerical Example

To demonstrate the procedure used to determine displacements at given stations, a numerical computation is presented here. Consider a running skyline with an equipment specification of

ω_1, haulback line weight per foot = 1.04 pounds per foot

ω_3, combined weight of main and slack-pulling line = 1.44 pounds per foot

T_A, haulback line working tension at headspar = 19,600 pounds

W_C, carriage weight = 1,200 pounds

with the anchoring geometry of

L, span between headspar and tailhold = 1,500 feet

h, anchor point vertical separation = 600 feet.

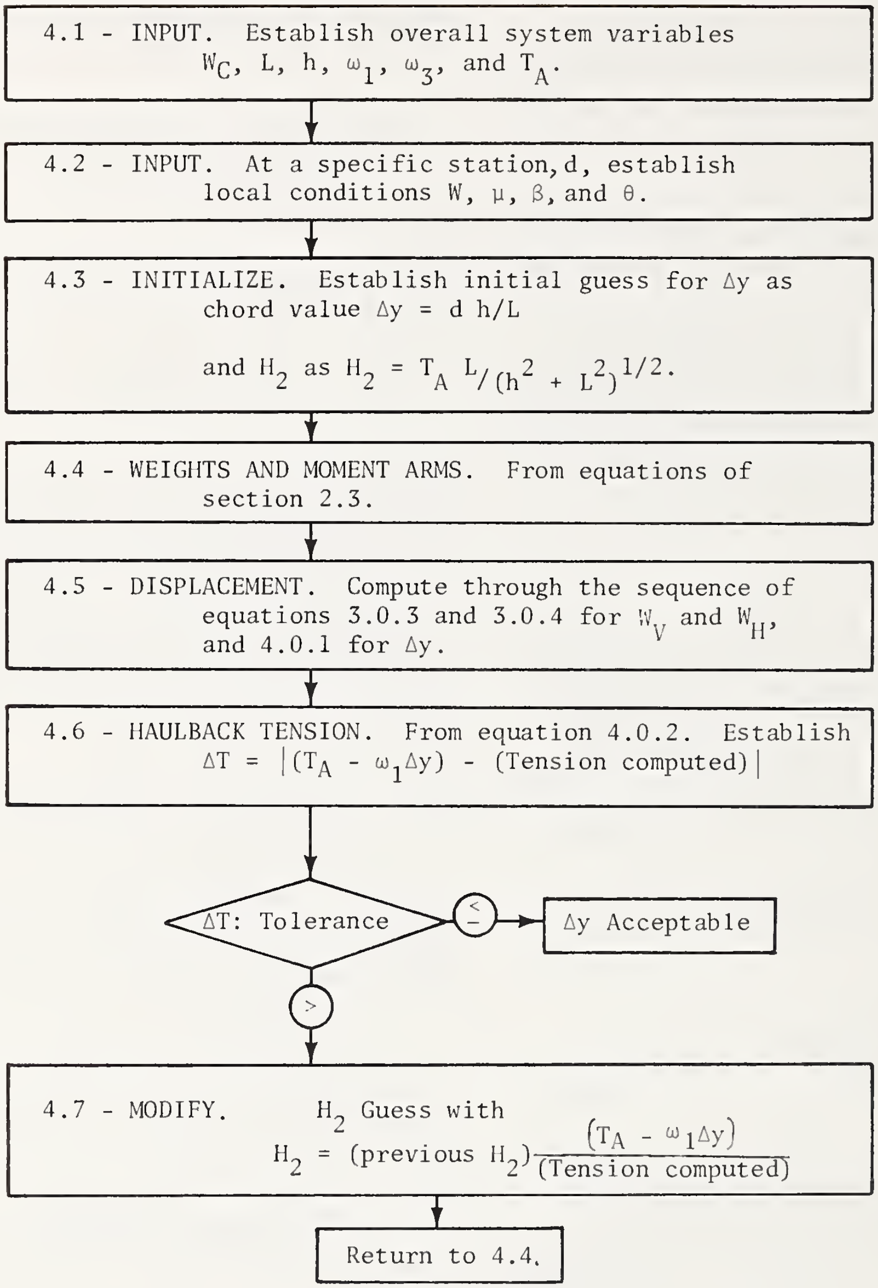

Figure 4.--Flow chart of solution procedure.

In this example, the displacement at the station d = 600 is determined, where the load conditions are given to be

W, log load, one end of which is supported by the ground = 10,000 pounds

μ, assumed coefficient of friction between the load and ground = 0.6

β, the angle of the load with respect to the ground = 5 degrees

and θ, the local ground slope = 23 degrees (42.45 percent).

With these conditions, the initial guess for displacement and horizontal tension are, respectively,

Δy = 240 feet

and H_2 = 18,198.14 pounds.

These values lead to initial values for the computed displacement and tension, respectively,

Δy = 319.21 feet

haulback tension computed = 19,551.38 pounds.

The tension discrepancy of ΔT = 48.62 requires another iteration which yields

Δy = 319.15 feet

and haulback tension computed = 19,595.48 pounds.

After four trials, the guess for Δy is 319.13 which yields a computed haulback tension within 0.01 pound of the required value of 19,600 pounds. The method has been used extensively in a program reported by Carson (1975) and has converged rapidly in all cases attempted.

6.0 Conclusions

This paper has presented a mathematical procedure which successfully models the forces and displacements that exist in a running skyline configuration with a dragging log load. The procedure has been programed for desk-top computer execution by Carson (1975). The description discussed here and used in Carson (1975) should provide the logging engineer with more realistic estimates of the conditions existing in a running skyline system.

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Experiment Station
P.O. Box 3141
Portland, Oregon 97208